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Review

Biofuel support policies in Europe: Lessons learnt for the long way ahead

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Abstract

Biofuel consumption in the EU is growing rapidly but major efforts will need to be undertaken if the EU's objectives for 2010 and beyond are to be achieved. This article analyses the strengths and weaknesses of different biofuel support policies based on the experiences gained in pioneering countries and explores scenarios for their possible impacts in the long-term. It comes to the conclusion that important pre-conditions such as fuel standards and compatibility with engines are in place or being introduced on an EU-wide basis. Current and future policy support therefore focuses on creating favourable economic or legal frameworks to accelerate the market penetration of biofuels. The ambitious targets endorsed in terms of biofuel market shares require the implementation of efficient policy instruments. At the same time, large consumption volumes and the advent of innovative production technologies make it possible for Member States to promote specific types of biofuels, depending on their main objectives and natural potentials. This will require complementary instruments such as subsidies for production facilities, user incentives or feedstock subsidies.
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Keywords: Biofuel; Policy instruments; Key drivers; Market implementation; Scenarios

Contents

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1. Introduction

Alternative transport fuels – i.e. hydrogen, natural gas and biofuels – are seen as an option to help the transport sector in decreasing its dependency on oil and reducing its environmental pressures while simultaneously ensuring mobility for EU citizens. Biofuels are considered to be most promising in the short-term as their market maturity is above those of the other options. They combine the advantage of a broad availability of the feedstock, an existing infrastructure and the compatibility with conventional engines within certain limits. Furthermore, biomass-based fuels may create alternative outlets for farm produce, therefore supporting rural areas.

The EU aims at achieving a 5.75% share of biofuels by 2010. This indicative target set by the EU biofuels directive [1] has been adopted by most Member States in their national biofuel objectives [2]. According to the conclusions of the European Council in March 2007 [3], the share of biofuels shall reach at least 10% of all diesel and gasoline transport fuels in the EU by 2020 under the condition that production can be done in a sustainable way, that second generation biofuels become commercially available and the fuel quality directive is amended. In order to promote the penetration of biofuels in the transport market, Member States apply a wide variety of measures, comprising command and control instruments (e.g. standards, quotas) as well as economic and fiscal measures, such as tax exemptions or reductions, and communication and collaborative measures [4]. On EU level, support is provided by offering Member States to apply a reduced rate of fuel taxes, through the creation of standards and via the Common Agricultural Policy that allows the cultivation of biofuel feedstock on set-aside land and creates the option of a premium for growing bioenergy crops. Furthermore, current EU legislation that limits the blending of biofuels into fossil fuels to 5% (in volume terms) is being revised to allow for higher shares.

The assessment of such biofuel policies is the subject of this paper. The analysis will take into account the rapidly growing market (Section 2), which implies the need for efficient instruments. Furthermore, with an increasing number of technological options becoming available, Member States will be able to better steer the market so as to promote biofuels with certain characteristics (e.g. those fulfilling sustainability criteria). This relationship between key drivers, potentials and the biofuel mix is assessed in Section 3. Section 4 introduces an indicator-based classification of Member States according to their main interest and potential in producing and consuming biofuels. In Section 5 different policy options are then evaluated based both on experiences gained in EU Member States and the results of modelling exercises. In Section 6, we conclude.

The selected model results, to which we will refer in this paper, were developed in the context of the European projects PREMIA and TRIAS [5]. The biofuel model used for this purpose is based on a recursive year-by-year simulation of biofuel demand and supply until 2030. For each set of exogenously given parameters an equilibrium point is found at which the cost of biofuels equals that of the fossil alternative they substitute, taking into account the feedback loops of agricultural markets and restrictions in the annual growth rates of additional biofuel production capacity. Biofuel production costs and well-to-wheel greenhouse gas emissions are primarily based on a joint study by JRC, EUCAR and Concawe [6]. The model was exploited to assess a number of different scenarios reflecting both different policy options as well as variations of key input parameters. They are described in detail in Ref. [7].

2. A developing biofuels market: efficient policies needed

The take-up of biofuels in the EU started off at a slow pace, with only a limited number of Member States actively promoting them. The dominance of these ‘pioneering countries’ is still salient today, despite the rapid market increases in recent years. By 2006, more than 80% of the total EU biofuels were produced by only four Member States namely Germany, France, Italy and Spain. Likewise, Germany, France, Austria and Sweden account for 84% of the total biofuel consumption (Fig. 1).

However, most Member States have now introduced biofuel support measures and biofuel consumption is increasing rapidly throughout Europe. Even if Germany and France continue to lead the EU market together with Spain, Sweden and Italy, countries like Austria, the UK, Portugal and Greece showed a sharp rise in their biofuels consumption due to the launch of recent biofuel policies. Also, it is worth mentioning that Eastern European countries are likely to play a growing role in the EU biofuels market in the coming years. They indeed present significant potentials related to the feedstock and biofuel production [10–12].

At an aggregated EU level, biofuel production and consumption grew by a factor 3.2 and 4 between 2003 and 2006, respectively. Growth in biofuel consumption between 2005 and 2006 almost reached 80% [8], leading to a share of biofuels in transport fuel consumption of 1.8% in 2006 [8]. This means that the EU indicative target of 2% set for 2005 was almost reached, albeit with a delay of 1 year.

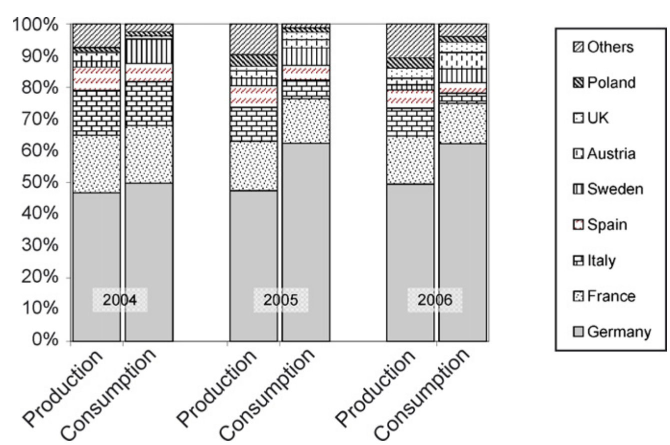

Fig. 1. Share of Member States in total EU biofuel production and consumption (derived from figures in toe, [4,8,9]).

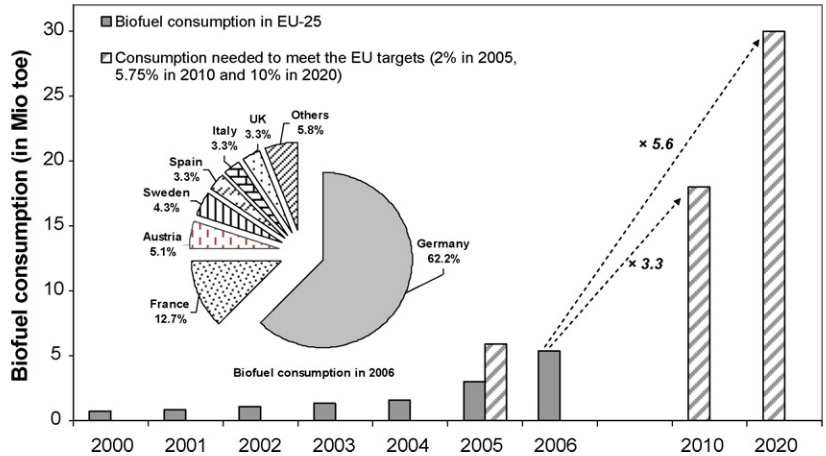

Fig. 2. Biofuel consumption in EU-25 and EU target for 2010 and objective for 2020 (data from [4,8,13]).

Pushed by political support, high oil prices and consumer awareness, a further growth of biofuels is expected. Nevertheless, meeting a share of 10% biofuels by 2020 entails a sixfold increase in consumption levels from 2006 levels (Fig. 2). As a consequence policy support for biofuels would need to continue. However, due to the large volumes involved, the measures will need to be efficient on the one hand, and capable of steering the market on the other, in order to, e.g. minimise revenue losses and ensure long-term sustainability.

3. Broadening technological options: steering the market to better meet objectives

Current production of biofuels relies on oily crops for biodiesel, and sugar/starch crops for bioethanol. While these conventional biofuel have the advantage of being a mature technology which is available at industrial scale, they have the disadvantage of depending on food crops. Furthermore, the savings of greenhouse gas emissions when replacing their fossil equivalent can be limited and in some cases even negative, depending on the production process.

Advanced (‘‘second generation’’) biofuel production processes are seen as promising technologies for the future as they can make use of a wide range of by-products (such as straw) and woody biomass with a higher availability, and lead to lower greenhouse gas emissions [6]. Compared to conventional biofuels, this implies a lower repercussion on food and fodder markets and enables the use of crops that are more environmentally benign [14]. However, advanced biofuels such as ligno-cellulosic ethanol or Fischer-Tropsch-diesel are currently at pilot stage and are expected to enter the market only in the coming decades [15].

This increasing number of available biofuel production pathways with different characteristics in terms of greenhouse gas emissions, production costs and potentials implies that Member States may employ differentiated biofuel strategies, favouring specific types of biofuels in order to better serve the objectives underlying their biofuel support policy.

The public policy support to biofuel consumption and production is generally motivated by the following key objectives:

- Creation of an alternative outlet for farm produce and development of rural areas;
- Reduction of greenhouse gas emissions from the transport sector;
- Increasing supply security by reducing the oil import dependency of the transport sector.

The weighting of these objectives usually varies between countries and time. While historically, the support to the agricultural sector (e.g. France, Czech Republic) and especially energy security were the main drivers (e.g. the Brazilian Proálcool support programme), combating greenhouse gas emissions has become an equally important goal for biofuel support in the EU (notwithstanding that other policies may be more efficient in reducing GHG emissions). EU Member States (except Malta and Cyprus) have agreed to limit or decrease their emissions of greenhouse gases under the framework of the Kyoto protocol. In 2005, transport accounted for 19% of total GHG emissions (excl. emission from land use and land use change) in the EU-27 and transport was the sector with the largest increase in GHG emissions compared to 1990 levels (+26%), offsetting the reductions achieved by other sectors of the economy [16]. Moreover, with the rise in oil prices over the past years, the transport sector's almost complete dependence on oil-derived fuels has become a major concern, and biofuels are often seen as one option to reduce this dependency to a certain degree.

Innovation may become an additional driver for some Member States. This relates mainly to the development of advanced biofuel technologies, for which an export market can be expected, looking for example at the US interest in ligno-cellulosic bioethanol to fulfil the ambitious biofuel targets.

Finally, with the large amount of feedstock needed to fulfil the rapidly increasing demand for biofuels, environmental sustainability of feedstock production will become an

	GHG emissions	Supply security	Agricultural income	Innovation	Soil, water, biodiversity
High share of imports	⇧⬇	⬇	⬇	uncertain	⇧⬇
High share of advanced biofuels	⇧	⇧	⇧⬇	⇧	⇧

Fig. 3. Relation between different biofuel strategies and underlying key drivers.

important key framework condition both for domestic and imported biofuels. Biofuels with high well-to-wheel GHG emissions and/or high negative impacts on agricultural and forest biodiversity, soil and water quality [14] are likely to become less attractive than sustainable biofuels.

Depending on which driver is prevailing, the focus of the policy will change. Fig. 3 suggests relations between the different key drivers for biofuel support and a biofuel strategy with regard to the share of imports and the share of advanced (second generation) technologies. The consequences of each of the drivers on the overall biofuel target are not taken into account as they depend on a number of additional assumptions. These interlinkages were developed in the framework of the PREMIA project and discussed at several regional stakeholder workshops [17].

If the prevailing driver for a biofuel policy is the reduction of GHG emissions, a policy supporting an accelerated introduction of advanced biofuels may be beneficial, since these technologies usually have lower per-unit GHG emissions than conventional ones. The impact of a GHG-driven biofuel policy on imports remains, however, ambivalent. Currently, the most common imported biofuel – sugar cane-based ethanol from Brazil – is available at lower costs and often lower GHG emissions than domestically produced biofuels. However, depending on the origin of the imports and the production processes, the favourable trend might change in the future, if, for example, biofuel production leads to deforestation. Also, biofuel imports from other world regions can have higher GHG emissions than domestically produced ones.

A biofuel policy that primarily aims at enhancing supply security would try to limit the share of imported biofuels. Nevertheless, it needs to be pointed out that biofuels or feedstock can be imported from a broad range of countries, unlike oil, thus reducing the risks of supply. In the long run, it is also likely that there would be more advanced biofuels, as these can use a broader feedstock base and thus have a larger domestic potential than conventional biofuels that are limited to sugar, starch and oil crops.

Limiting import levels would be one consequence if a biofuel policy primarily aims at creating alternative outlets for agricultural products. At the same time, first generation biofuels may benefit from such an approach, as they depend on agricultural crops, while for advanced biofuels cheap by-products would be used rather than dedicated agricultural crops. On the other hand, as a co-existence between conventional and advanced technologies can be expected for the medium term, the net effect on agricultural income is likely to be positive. Furthermore, agricultural by-products can be converted (e.g. straw) which would ensure an additional income for farmers. Eventually, advanced technologies can make use of crops that can be grown on poor soils and in arid climates, thus opening up new opportunities for farmers.

Policies that foster technological innovation and avoid lock-in on established technologies would promote advanced biofuels. Innovation is, however, not restricted to processing technologies, but includes research on more efficient oil and starch and ligno-cellulosic crops [18], which in return may result in a reduction of imported biofuels.

Production of feedstock for biofuels can have an adverse impact on soil and water resources as well as biodiversity if grown in sensitive areas and without considering these factors. The impacts can be high for some imports (e.g. if rainforest was transformed into arable land). On the other hand, growing energy crops on tropical lands can result in much higher yields and thus less demand of area. A general net effect of focusing the biofuel support on environmental functions cannot be deducted. A clear impact would occur with regard to the introduction of advanced biofuels. These would be pushed as they can use a broader range of feedstock, in particular multi-annual crops (and by-products), which generally have a lower risk of erosion and nutrient and pesticide leakage than annual crops [14].

It is likely to assume that there are major differences in the prevailing key drivers for supporting biofuels among the EU Member States. In the following section, an indicator-based characterisation of EU Member States according to their potential and interest in actively supporting biofuels is introduced.

Overall, upcoming innovative technologies and larger market volumes will allow for a differentiation of the biofuel markets so that Member States can choose a strategy that best suits their underlying key drivers. This implies that policies and measures shall be analysed not only with regard to their efficiency, but also to their ability to favour certain types of biofuels (Section 5).

4. Member States: varying potentials and interest

As is illustrated in Section 3, the suitability of a certain biofuel strategy will depend on the objectives underlying the policy. An indicator-based clustering of EU countries according to their potential interest in producing biofuel feedstock and consuming biofuels was therefore developed.

The indicators selected relate to the overall economic strength of a country combined with energy demand in transport and the importance of the agricultural sector, since

these are the most important characteristics of a country with regard to biofuels. They include GDP, arable land per capita, the share of the agricultural sector in overall employment, transport energy demand and CO_2 emissions as well as oil import dependency of a country. The underlying data is mainly based on Eurostat up to 2004. All indicators are expressed as a score ranging from 0 to 5 instead of absolute values, in order to enable their combination. For example, a country independent from oil imports would be associated to score 0, while a country that completely depends on imported oil will be given the score 5 (see Refs. [19,20] for more details).

In order to derive an integrated indicator suggesting a country's interest and potential in biofuel feedstock production, and another one presenting the interest in increasing biofuel consumption, the above indicators are combined through weighting factors (see Table 1). These factors represent the importance of different key drivers in the respective integrated indicators, and are based on an expert consultation.

Countries with a high level of rural employment and income are presumed to have a genuine interest in biofuels as an option to create alternative outlets for agricultural produce. Furthermore, it seems likely that those countries with a major arable area will be more interested in setting up an active biofuel policy as they would be able to domestically produce important amounts of biofuels.

The *x*-axis in Fig. 4 indicates that particularly Lithuania, Bulgaria, Denmark, Poland, Romania, Hungary and France can be classified as countries with an elevated interest in agricultural feedstock production. As such, they are candidates in increasing domestic production of biofuels. Nevertheless, this also depends on the competitiveness of conventional agricultural products, which determines whether there is a need for the agricultural sector to switch to alternative products. Furthermore, the picture will get more complicated, when advanced biofuels are taken into account. In this case, agricultural by-products or forestry (by-) products can be used as feedstock, so that additional indicators such as the forest areas will gain importance. Finally, a country may decide to grow energy crops but to use them mainly for electricity and heat instead of biofuel production.

On the other hand, Member States that combine the economic capability (high GDP) with high transport energy demand and related oil import dependency as well as elevated CO_2 emissions per capita are considered having a greater interest in increasing biofuels consumption. This assumption implies that most of the pre-2004 EU-15 Member States could

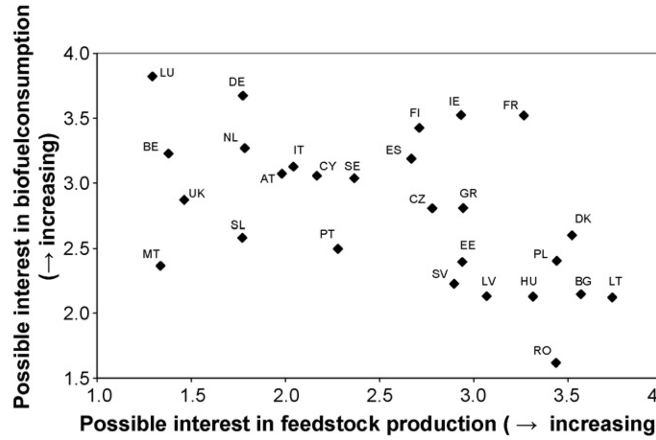

Fig. 4. Member States' interest to support biofuel consumption vs. interest to support feedstock production.

have an elevated interest in increasing the consumption of biofuels, led by Luxembourg and followed by Germany, France and Ireland. Germany and France have indeed already implemented an ambitious biofuel policy. Germany is currently leading the European market, driven by strong agricultural and industrial sectors and a very favourable legislation for biofuels (up to the end of 2006).

Member States that combine both a high interest in consumption with a high potential for feedstock production (such as France and Spain) often have been at the forefront of promoting biofuels. France has been the leading player on biofuels in Europe in the 1990s, driven by the strong agricultural and industrial sectors. From 2000, the biofuel share on the market was controlled by an accreditation (quota) system, which stabilised the market, but also prevented growth as the market was limited to a few big industrial players. French government has now announced ambitious plans for the coming years, aiming for 10% biofuels by 2015. Spain has become the leading Member State in ethanol production. The Swedish success story is mostly driven by local initiatives, supported by local and national governments [21]. Even though Sweden imports large amounts of ethanol, there are plans to use the large potential of woody biomass for producing ligno-cellulosic ethanol in the future. It has to be noted that Austria, which is one of the pioneering countries in the EU, is also close to this group and would certainly fall within it if the definition of feedstock was extended to also cover woody biomass. Also Italy, an important producer of biodiesel, comes close to this group.

Table 1
Construction of integrated indicators

	Economy	Agriculture	Energy demand, oil import and CO_2 emissions
Indicators	GDP (in PPS); GDP (in EUR)	Arable land (corrected for yield) per capita; share of agricultural employment in overall	Transport energy demand per capita; oil import dependency; number of vehicles per capita; CO_2 emissions
Weighting factors for biofuel consumption interest	40%	10%	50%
Weighting factors for biofuel feedstock production interest	10%	90%	0%

Nevertheless, this indicator needs to be interpreted with care as it only provides a snapshot of the current situation. The expected increase in energy import dependency in many countries is not reflected, but may be an important driver for a future-oriented biofuels policy. The development of transport-related CO_2 emissions also needs to be set into context of the overall trend in CO_2 emissions in a country.

Overall, while the above clustering can well provide an indication of the theoretical interest and potential in biofuel production and consumption, it does not reflect the political commitment of a government to promote biofuels. The latter, however, has a high impact on the penetration of biofuels in a given country [22]. The importance of this factor can be fully conceived if one examines the different examples in the European region and the success of biofuels on the market. Ireland, for example, seems to present all the characteristics to support a biofuels strategy according to the indicator-based assessment. In reality, however, its government was reluctant to support such a move until recently, resulting in a low share of biofuels in its transport market.

5. Biofuel support policies and measures

The changing framework that was described in Sections 2–4 implies for a future biofuel support policy the need to be efficient while simultaneously enabling Member States to differentiate the market in order to best meet their objectives. Within this context, a number of instruments are being analysed in the following, based on the experiences gained in some countries and sometimes referring to scenarios developed within the PREMIA project [7].

A large variety of biofuel support policies are in place in EU Member States, ranging from command and control instruments such as standards and quotas, over economic and fiscal measures, such as tax exemptions, to information diffusion. Furthermore, they address different stages of the biofuel chain, i.e. covering R&D for new technologies as well as market diffusion. A detailed overview of the measures applied by individual EU Member States can be found in [4,23].

As (conventional) biofuels are a mature fuel, the policy focus today often lies on facilitating their market entry rather than R&D support. This implies that market demand is created by policies, as the production costs of biofuels lie above those of fossil fuels (unless very high oil and/or carbon dioxide emission prices are attained). This can be done through basically two instruments: subsidisation or prescription of a mandatory production.

Under the first scheme, biofuels are subsidised so as to reduce the price level to that of fossil fuels (or below). The second approach consists of prescribing a fixed quantity of biofuels to be supplied by fuel suppliers on an obligatory basis. The first option is implemented by a tax reduction scheme, which has proven successful although it caused important revenue losses for government. In the second option, fuel suppliers are obliged to achieve a certain biofuel share in their total sales. Here, fuel suppliers and ultimately the transport users will carry the additional costs. Both instruments can be complemented by a number of other incentives, such as support to dedicated vehicles. These instruments will be assessed in the following.

5.1. Tax reductions

The EU Energy Taxation Directive [24] sets the framework for this instrument for Member States by allowing exempting biofuels from taxes under the conditions that:

- The tax exemption or reduction must not exceed the amount of taxation payable on the volume of renewables used;
- Changes in the feedstock prices are accounted for in order to avoid overcompensation;
- The exemption or reduction authorised may not be applied for a period of more than six consecutive years, renewable.

Past experience shows that partial or total exemptions from fuel taxes for biofuels were vital in promoting biofuels in the EU. All Member States with a high penetration of biofuels have, or have had, a favourable tax regime in place, e.g. Germany (until the end of 2006), France, Sweden, and Spain. National tax incentives have also played a major role in the USA, which have become the largest producer of fuel ethanol worldwide.

As the tax exemption must not exceed the level of the fuel tax, the instrument has proven most successful in countries with fossil fuel tax levels that compensate the additional production costs of biofuels compared to the fossil alternatives. This relation becomes very clear for Germany, where the introduction of a continuously rising ecotax on fossil fuels from 1999 onwards combined with a full tax exemption for biofuels eventually led to biodiesel pump prices falling below those of fossil diesel. As a result of a tax exemption of 47 ct/l for biodiesel in 2005, the highest level among EU Member States (Fig. 5), biodiesel accounted for more than 6% of all diesel sold in Germany at that time (in energy terms).

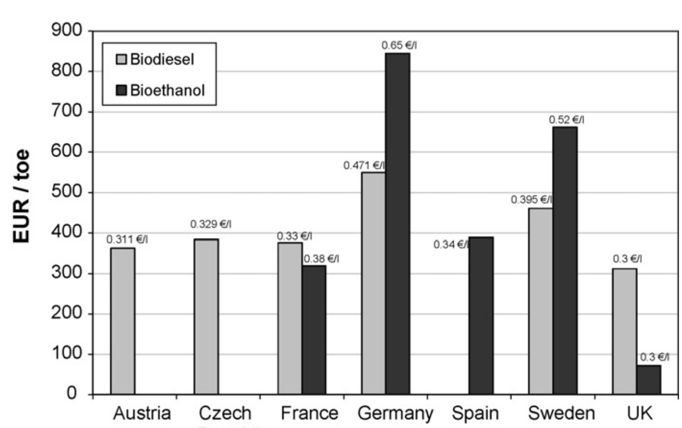

Fig. 5. Level of tax reduction (in €/toe) in 2005 by Member State (the corresponding tax reduction level in volume term is also indicated for information). Source: based on Pelkmans et al. [4]. *Note*—energy contents used: biodiesel, 33.1 MJ/l; diesel, 35.9 MJ/l; bioethanol, 19.6 MJ/l; gasoline, 32.2 MJ/l.

The German case also illustrates the main drawback of this instrument: losses of fuel tax revenue amounted to 1140 Mio € in 2005. In France, revenue losses were in the order of 200 Mio € and around 160 Mio € in Sweden. The total revenue losses in the EU-25 are estimated to be between 1.5 and 2 bn € for 2005 [4]. It needs to be noted that a way of overcoming the revenue losses may be a simultaneous increase in the fossil fuel tax so as to render the policy budget-neutral, as done in Belgium.

With increasing volumes of biofuel consumptions, the revenue losses become even more important. According to scenario results [7], achieving a 10% biofuel share in the EU-25 at an oil price of 65 US$/bbl (50 €/bbl) and a maximum import rate of 30% would result in tax revenue losses of 7.6 bn € in 2020, or some 80 bn € cumulatively between 2007 and 2020. These costs are calculated as additional production costs of biofuels and consequently do not take into account any kind of potential overcompensation. Furthermore, they assume that the lowest cost biofuels are implemented, ignoring that governments may decide to favour different types of biofuels to, e.g. better support their domestic agriculture or reduce GHG emissions. On the other hand, the figure also ignores the potential benefits of biofuels to society that may arise through enhancing supply security, reducing GHG emissions or creating alternative sources of income to farmers. According to the model results, a 10% biofuel share could save more than 630 Mio. t CO_2-eq and around 300 Mtoe (12.6 EJ) of fossil fuels between 2007 and 2020. It must be noted, however, that these figures do not include systemic effects that could arise from an increasing demand of biofuel feedstock and may thus overestimate the greenhouse gas savings. For example, land use changes (e.g. conversion of permanent grass land or tropical forest to arable land for growing biofuels) and the related release of substantial amounts of soil carbon are not included.

Another feature of tax exemptions is their ability to steer the market by applying different reduction rates to various types of biofuels. In Germany, for example, only pure biofuels entered the market before 2004, as blends did not profit from tax reductions. This meant that the German market was almost entirely dominated by biodiesel, which can be used as a pure fuel with only minor modifications to the engine compared to pure ethanol. After the extension of the support scheme to include biofuel blends, low-blends rapidly gained an important market share. Furthermore, by 2006, Germany had become the major ethanol consuming Member States, followed by Sweden and France [8].

5.2. Obligations to fuel providers

The most direct way of increasing the share of biofuels is by establishing obligatory substitution levels for the transport fuel sold to consumers. The obligation falls onto the oil companies/fuel distributors to sell a certain share or a fixed amount of biofuels, which may in return imply that this instrument is more difficult to implement. It is very reasonable to assume that the additional costs would eventually be passed on to the final transport users.

One of the major advantages of the obligation to fuel suppliers is the predictability of the market volumes that will be reached in a certain year. As the fuel supplier is obliged to fulfil the quota, this is the expected amount that will enter the market, unless an alternative mechanism seems more attractive. An obligation system thus sets a long-term, predictable framework to the biofuel producers, which consequently have a higher investment security, compared to the case of tax exemptions that can be revised every year, depending on the States' income needs. On the other hand, if the annual targets are set too low, the obligation may not exploit the full potential of biofuels.

In theory, the average direct cost for each litre of conventional fuel displaced would be similar to the one in the tax reduction case, the main difference being that the effects on the government budget would be almost neutral (apart from implementation and monitoring costs, and second-order effects to the economy). Costs would be carried by the oil industry and are likely to be passed on to the final transport users through higher fuel prices. This in return may reduce transport demand compared to a tax exemption scheme borne by the government, which is, however, rather supportive to the key drivers underlying biofuel support.

Eventually, the systems will also result in different second-order effects to the economy due to changes in government

Table 2
Distribution of impacts related to the two main policy tools

Actor	Main impacts of tax reduction	Main impacts of obligation
Government	Loss of tax revenue equal to the subsidy	Second-order effects of increased costs for the economy
Transport users	No impacts	Increase of costs proportional to blending level
Consumers	Second-order effects from changes in government spending and increase in food prices	Second-order effects from reduction of disposable income (fuel and food prices, marginally manufactured goods and services)
Refineries	Reduction of sales of conventional fuel; marginal reduction in profits	Reduction of sales of conventional fuel; implementation costs; marginal reduction in profits
Agricultural sector	Increase in income; marginal increase in employment (set-aside land and sugar reform)	Increase in income; marginal increase in employment (set-aside land and sugar reform)
Agriculture related sectors	Increase in input costs (oils), stabilisation of sugar price; fluctuations in substitute products	Increase in input costs (oils), stabilisation of sugar price; fluctuations in substitute products
Industry and services	Second-order effects from changes in government spending; third-order effects from change in disposable income of consumers	Second-order effects from increase in transport costs; third-order effects from change in disposable income of consumers

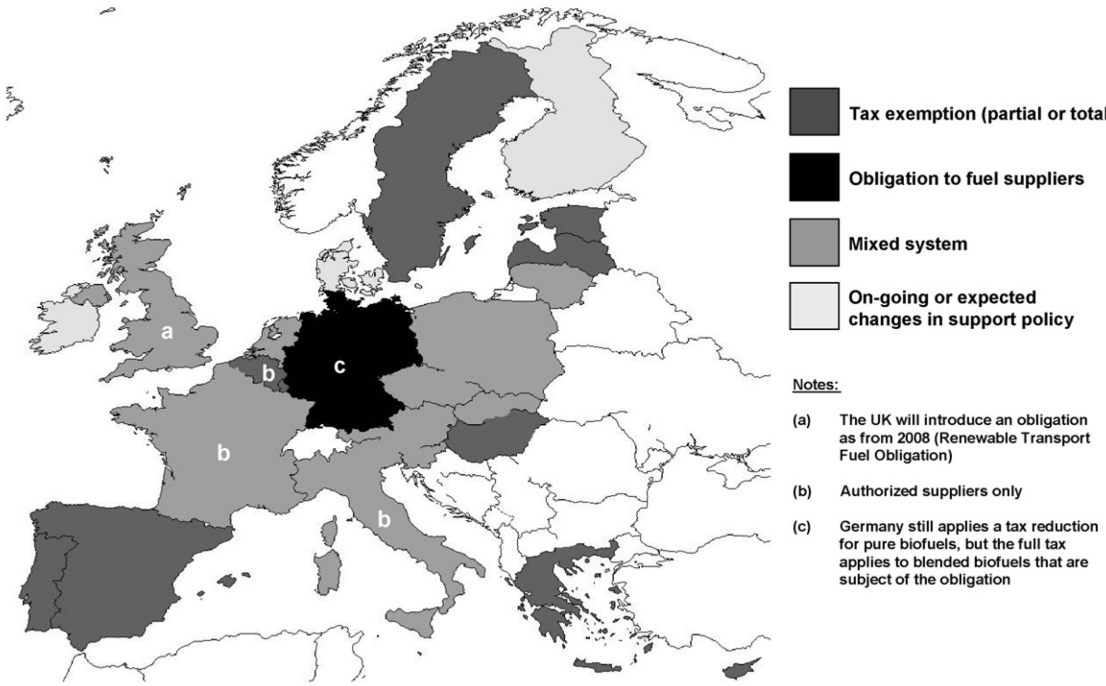

Fig. 6. Biofuel support schemes in Europe.

spending in the one case, or higher transport costs in the other. These effects are summarised in Table 2.

Modelling results for alternative scenarios indicate that the additional costs for meeting the 10% biofuel target with an obligation would amount to 7.6 bn € by 2020, similar to the results for a tax exemption scheme [7]. The cumulative costs might, however, be below that of a tax exemption scheme as the model assumes a logistical introduction of biofuels for the latter, while the assumed obligation scheme would result in a linear target pathway. If the difference of production costs between fossil fuels and their biofuel substitutes are directly passed on to the transport users, these would need to pay an additional price of around 2.5 €-cents per litre of all fuel sold by 2020 in a least-cost approach.

A switch towards obligation schemes can recently be observed as a consequence of the high revenue losses resulting from tax exemption schemes. Since 2005, 12 EU Member States – accounting for almost 90% of the total EU biofuels consumption in 2006 – have switched or will switch from a tax exemption to an obligation or mixed scheme in the very short-term, reflecting the need for efficient support systems (see Fig. 6). In many Member States, some mixed schemes are in place, in which quotas either limit the amount of biofuels that will benefit from a tax exemption, or tax exemptions only apply to certain biofuels while the large volume biofuels fall under an obligation scheme.

France introduced already in 2005 a mixed system with the TGAP (Taxe Générale sur les Activités Polluantes) that can be considered as a ‘‘quasi-obligation’’ system in the sense that fuel suppliers who do not incorporate a fixed amount of biofuels have to pay the tax; it consequently acts like a penalty occurring when an incorporation rate is not attained. Austria and Slovenia introduced an obligation in 2005 and 2006, respectively. Germany, the Netherlands and Poland changed towards an obligation system by 2007; the UK will introduce a renewable transport fuel obligation as from 2008. Ireland recently announced the introduction of a biofuels obligation from 2009. Also in Finland, legislation proposing a biofuels obligation is pending. Only two major players namely Spain and Sweden have not moved to an obligation or mixed system.

Despite the advantages for the public budget, an obligation system contains a number of potential drawbacks. One of the major risks is related to the incentive for fuel suppliers to opt for the lowest cost biofuels. While this ensures achieving a certain share of biofuels at low costs, it risks at having drawbacks on fulfilling the key objectives behind the biofuel support unless additional instruments are employed to steer the market. A likely effect is, for example, a higher share of imports, resulting in less support to domestic agriculture. Also low-blend fuels are likely to be favoured, and fewer incentives for innovation created.

This means that obligations may be an efficient instrument for increasing biofuel consumption, but are less appropriate for promoting a special type of biofuel. Other or complementary policies will prove more effective in pushing pure or high blends or certain technologies.

5.3. Complementary policies and measures

In addition to the main instruments that primarily aim at creating a market demand – tax reduction and obligation – a variety of other, often complementary policies exist. These comprise supply side measures such as agricultural feedstock support or grants to production facilities as well as demand side measures such as the promotion of dedicated biofuel vehicles. While their impact on the overall promotion of biofuels has

been rather limited in the past, they may become important additional instruments in the future as they allow the promotion of some specific biofuel production pathways. On the other hand, all complementary measure cause additional direct costs compared to a least-cost approach.

Support to the cultivation of agricultural feedstock production in the EU is determined by the Common Agricultural Policy. Since 1992, bioenergy crops may be cultivated on set-aside areas that do not allow for the production of food crops up to a certain amount, agreed upon in the Blair House Agreement. The 2003 CAP reform also introduced a special aid for energy crops of 45 €/ha to support the cultivation of bioenergy feedstock [25]. This energy crop premium was recently extended to a maximum area of 2 million hectares (up from 1.5) and covering all Member States [26].

Farmers have used the energy premium to a large extent. By 2006, the energy premium was applied on almost one half of the land used for bioenergy production, another third was grown on set-aside land. Nevertheless, the extra revenues for the farmers remain limited: with an average yield of 3–4 tons of rapeseed per hectare, the premium would create extra revenue of 10–15 €/ton, on top of the market price of 200–250 €/ton. Moreover, the instrument is not suitable for reducing the overall production costs of biofuels: production costs are estimated to be reduced by only 0.03–0.04 €/l for biodiesel and by 0.01–0.02 €/l for bioethanol [4].

In the medium term, this scheme can nevertheless become a suitable instrument for guiding the biofuel market to promote certain type of crops. Member States might, for example, create an incentive for dedicated energy crops that combine a high yield with limited environmental impacts [14]. A first step in this direction was already made with the reform of the energy crop premium by including multiannual crops. Also the PREMIA biofuel scenarios indicate the potential of this policy in pushing advanced biofuels based on multiannual crops [7].

Capital investment support to biofuel production facilities is another supply side instrument. So far, however, it has only played a limited role in promoting biofuels. This is largely due to the fact that for conventional biofuel production facilities, the fixed costs are rather small compared to the cost of feedstock. According to [6], they are in the range of 7% (biodiesel) to 30% (bioethanol).

This may change drastically with the advent of advanced second generation biofuel technologies. Here, fixed costs account for the large part (more than 60%) of total production costs. A capital investment subsidy is thus well suited to promote advanced biofuel technologies in their infant stage. The scenarios developed within the PREMIA project illustrate this effect: assuming a subsidy covering 50% of the capital costs of the production facilities on top of a biofuel obligation scheme, the share of ligno-cellulosic ethanol in total fuel demand might increase by a factor of 10 [7]. On the other hand, however, such a complementary policy leads to additional costs that are borne by governments.

On the demand side, *user incentives* have proven to be an effective, yet complementary instrument when (major) adaptations to vehicles are required. Sweden has created a number of user incentives for promoting flexi-fuel vehicles (FFV) that can run on high blends of ethanol. Such incentives include a 20% relief of company car taxation and the exemption from the Stockholm congestion charge as well as free parking for eco-friendly vehicles. In consequence, FFV vehicles make a share of 10% of newly registered vehicle sales, and about 1% of the total numbers of passenger cars are FFVs.

Biofuel standards are a necessary precondition for the wide market introduction of biofuels. They can help to build up trust of consumers, car manufacturers and fuel suppliers in the new product by ensuring a constant fuel quality. Moreover, EU-wide standards simplify biofuel trade.

All Member States with a successful biofuel penetration introduced standards at an early stage: biodiesel standards were introduced as early as 1991 in Austria, followed 1992 and 1994 by France and Germany. Inversely, the lack of clear biofuel standards has had a detrimental effect on consumer's confidence into biofuels in Poland [22]. Resulting from the national standards, an EU wide biodiesel standard was introduced in 2004 (EN14214); a similar EU-wide standard for bioethanol is being recently proposed (pr EN 1376).

On the other hand, the European standards for fossil gasoline (set by the EU fuel quality directive) and diesel (through the CEN diesel standard EN590) currently limit the blending of biofuels to 5% in volume terms. However, recent proposals call for an increase of these maximum shares in the context of the revision of the fuel quality directive and the norm EN590 [27].

5.4. Synthesis of support schemes

The different policies and measures discussed above are summarised in Table 3 (based on [4]). For all measures, their application phase from R&D to mature markets, main impacts, costs and long-term prospects are indicated. The costs are a rough estimate and are subject to a number of factors, including feedstock and oil prices as well as technology learning. Prospects describe the potential importance of the measure vis-à-vis the changing framework with larger market volumes and a broader range of available production pathways.

6. Conclusions and outlook

Biofuels are often considered as an option to help meeting the challenge of reducing oil dependence and greenhouse gas emissions in the transport sector. A broad variety of biofuel support policies have thus been launched at EU and Member State level. So far, however, the main part of the EU's biofuel production and consumption is concentrated in a few Member States (Germany, France, Italy, Austria, Sweden, Spain). In order to achieve the EU 5.75% biofuel target by 2010 and the 2020 objective, further support would be needed in all Member States.

Key preconditions for a wider market introduction of biofuels are fulfilled on an EU level, due to early efforts in pioneer countries such as Austria, Germany, France and Sweden. An EU-wide fuel quality standard for biodiesel exists since 2004 and a bioethanol standards is being proposed.

Table 3
Synthesis of selected policies and measures for supporting biofuels and impacts

Process chain	Measure	Application phase	Impact	Cost	Direct cost carried by	Prospects
Supply: feedstock	Subsidies of energy crop growth	Up to limited market share	Use of set-aside had clear impact	Limited to 45€/ha =>effect up to 0.5€/GJ (compared to total production cost of 17€/GJ)	Government	May be used to direct feedstock to crops with high yields and lower environmental pressures
Supply: conversion	Investment support for production facilities	Demonstration up to first market introduction	Useful to overcome high investment costs in the first stage of technology	Limited; equivalent to 0.5€/GJ (can be higher for prototypes, smallscale and first commercial systems)	Government	Important for advanced biofuel production plants with higher capital costs than conventional plants
Supply and Demand	Fuel standards	From first prototypes	Necessary for market introduction	Limited to research funding	Government/ industry	Crucial for ensuring market penetration
Demand: end users	Tax reduction	Up to limited market share; for high market share differentiation is possible according to external impact and calorific value	Makes alternative fuel cost-competitive. Success if production sector follows	High (ca. 10–17€/GJ)	Government	Proven to be successful to initiate markets if combined with high fuel taxes. For more mature markets, revenue losses become very high
Demand: fuel suppliers	Mandates for fuel suppliers	Limited market share	Stabilise market share, long-term prospects. Fast market response if supply of feedstock/biofuel is assured. Could restrict the market if quota set too low	High	Fuel consumers & distributors → eventually transport users	No revenue losses for governments and may thus be applied for more mature markets, too. Favours low blends, thus may require more complementary measures
Demand: end user	Vehicle compatibility	Prototypes and first demonstrations	Very important for later market introduction	Limited to research projects	Vehicle manufacturers, government research	Crucial step, both for low blends (general warranty) and high blends (dedicated vehicles)
Demand: end user	Direct user incentives	Up to limited market share	Direct advantages can create high public response	Limited	Governments	Is of importance especially for high blends that require adapted vehicles

Standards proved indispensable for facilitating creating reliable framework conditions that raise confidence of stakeholders (i.e. consumers, car manufacturers, fuel producers and suppliers) in the product. Furthermore, a high number of car engines are compatible with low blends of biofuels and there is an increasing market availability of vehicles that can use high blends or pure biofuels.

Most Member States have also introduced an active biofuel support policy in recent years and developed domestic production capacities. Despite different national objectives underlying the promotion of biofuels, this converging trend is likely to continue. Overall, biofuels are now in the process of passing from an initial pioneering stage to a more mature market on the EU level, despite differences among EU Member States. Similarly, a wide range of mature technologies is available and more promising advanced technologies are likely to enter the market in the coming decade. These changing framework conditions will also influence the choice of the most suitable mix of policy instruments.

The need for efficient instruments becomes obvious with regard to the large market volumes that are aimed at. Scenario calculations estimate the additional production costs of a 10% biofuel target to reach 7.6 bn € by 2020 (at an assumed oil price of 65 US$/bbl), yet not taking into account potential benefits to the society that may arise from greenhouse gas savings and reduced oil imports.

So far, subsidies through partial or total tax exemptions (complemented by other measures) have proven to be the most successful instrument in creating a market niche for biofuels. This has been the case particularly in countries with high taxes on fossil fuels, where the tax exemption could compensate the higher production costs of biofuels. However, while tax exemptions seem to be one key instrument in creating a niche market for biofuels, the losses in revenues for governments become high with rising market volumes, unless the fuel taxes will increase so as to have a budget-neutral policy. Over the past 2 years, a number of Member States have therefore moved towards obligation or mixed systems to lower the revenue losses.

Under a biofuel obligation, the additional costs are carried by fuel suppliers and eventually transport users. The instrument thus provides a strong incentive to opt for least cost biofuel strategies. On the other hand, this implies that complementary measures become necessary if certain types of biofuels shall be particularly promoted. This may be desirable as the share of imports, the choice of feedstock, or the dominance of conventional (first generation) or advanced (second generation) technologies strongly influence the impact of a biofuel policy on avoided greenhouse gas emissions, security of supply or agricultural income.

An indicator-based assessment of the potentials and interests in biofuel consumption and/or biofuel feedstock production reveals important differences among the EU Member States, with the new Member States generally having a large production potential. Many EU-15 Member States often have a higher need to reduce their GHG emissions and oil dependence in the transport sector, thus pushing consumption of biofuels.

The significance of measures on the supply side may therefore increase as a tool to steer a growing biofuel market into the desired direction, yet at an additional cost compared to a least-cost approach. A crop-specific feedstock support subsidy like the energy crop scheme may help to direct the crop mix into an environmental- and landscape-beneficial pathway. Investment subsidies for production facilities may become more important in the future if more advanced biofuels are desired.

Overall, it can be concluded that the preconditions for a wide market uptake of biofuels are fulfilled at the EU-level. A number of Member States also demonstrates successful ways of increasing the biofuel penetration. If the large consumption levels envisaged in the medium term are to be achieved, an efficient policy mix is required in order to limit the additional costs. Furthermore, the large market and the widening number of technological options make a differentiation of the market possible and desirable. This can be achieved through complementary policies that so far played a minor role.

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References

[1] Directive 2003/30/EC of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport.
[2] Member States' Reports in the frame of Directive 2003/30/EC, 2004, 2005 and 2006 reports.
[3] Presidency Conclusions. Council of the European Union. Brussels European Council; March 8/9, 2007.
[4] Pelkmans L, Portouli E, Papageorgiou A, Georgopoulos P. Impact assessment of measures towards the introduction of biofuels in the European Union. Report of Work Package 4 of the PREMIA project; 2006.
[5] Websites: www.premia-eu.org, www.isi.fraunhofer.de/trias.
[6] CONCAWE, EUCAR, JRC. Well-to-wheels analysis of future automotive fuels and powertrains in the European context, WELL-to-WHEELS report, Version 2b; May 2006.
[7] Wiesenthal T, Schade B, Christidis P, Leduc G, Pelkmans L, Govaerts L. Analysis of biofuel support policies. In: Proceedings of the 15th European Biomass Conference; 2007.
[8] EurObserv'ER. Biofuels Barometer-5.38 Mtoe consumed in 2006 in the EU; May 2007.
[9] European Biodiesel Board http://www.ebb-eu.org/.
[10] Kondili EM, Kaldellis JK. Biofuel implementation in East Europe: current status and future prospects. Renew Sust Energy Rev 2007;11:2137–51.
[11] van Dam J, Faaij APC, Lewandowski I, Fischer G. Biomass production potentials in Central and Eastern Europe under different scenarios. Biomass Bioenergy 2007;31(6):345–66.
[12] VIEWLS. Environmental and economic performance of biofuels. Report for the project VIEWLS (clear views on clean fuels); April 2005.
[13] COM 848 final, European Commission: Commission staff working document – Renewable Energy Roadmap – Summary of the impact assessment; 2006.
[14] European Environment Agency. How much bioenergy can Europe produce without harming the environment? EEA Report 7/2006.
[15] Hamelinck CN, Faaij APC. Outlook for advanced biofuels. Energy Policy 2006;34(17):3268–83.

[16] European Environment Agency. Annual European Community greenhouse gas inventory 1990–2005 and inventory report 2007. Submission to the UNFCCC Secretariat. EEA Technical Report 7/2007.

[17] Wiesenthal T, Leduc G, Christidis P, Pelkmans L, Georgopoulos P. Assessment of biofuels policies in Europe—lessons learnt and future policy options, Report of Work Package 7 of the PREMIA project; 2007.

[18] European Commission DG JRC, European Environment Agency. Sustainable Bioenergy cropping systems for the Mediterranean. Expert consultation; February 9–10, 2006.

[19] Govaerts L, Pelkmans L, Georgopoulos P, Wiesenthal T. Country specific conditions for the introduction of biofuels in Europe. In: Proceedings of the 15th European biomass conference and exhibition; 2007.

[20] Bekiaris E, Georgopoulos P, Papageorgiou A, Pelkmans L, Govaerts L, Wiesenthal, T. Towards introduction of alternative motor fuels: country-specific situations. PREMIA WP5 report; March 2007.

[21] Mc Cormick K, Peck P, Kaberger T. Breaking dependence on oil in Sweden: exploring the implication for biofuels. Energy Sust Dev 2006;10(2):127–8.

[22] van Thuijl E, Deurwaarder EP. European biofuel policies in retrospect. ECN May 2006.

[23] Pelkmans L, Govaerts L, Georgopoulos P, Portouli W, Wiesenthal T. Assessment of measures to support biofuel introduction in European countries. In: 15th European Biomass Conference and Exhibition; 2007.

[24] Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity.

[25] Council Regulation (EC) No. 1782/2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers and amending Regulations (EEC) No. 019/93, (EC) No. 1452/2001, (EC) No. 1453/2001, (EC) No. 1454/2001, (EC) No. 1868/94, (EC) No. 1251/1999, (EC) No. 1254/1999, (EC) No. 1673/2000, (EEC) No. 2358/71 and (EC) No. 2529/2001.

[26] COM 500 final, Commission staff working document—Annexes to the report from the Commission to the Council on the review of the energy crops scheme (under Article 92 of Council Regulation (EC) No. 1782/2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers); 2006.

[27] Directive 2003/17/EC of the European Parliament and of the Council of 3 March 2003 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels.